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CANADIAN FORCES AIRCREW

EJECTION, DESCENT, and LANDING INJURIES

1 JANUARY 1975 - 31 DECEMBER 1987

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ABSTRACT

During the 13 year period from January 1975 through December 1987, there were 78 attempted ejections from Canadian Forces (CF) aircraft of which 67 were successful. Fifty-eight of these ejectees received injuries from four main causative mechanisms: harness (restraint and parachute), body contact with cockpit surroundings during ejection, windblast force, and ejection acceleration force. Nineteen individuals (28.3%) received "major" injuries (dislocations, fractures, connective tissue injury, and organ contusion) from ejection jolt, windblast flail, collision with the seat structure, and landing. Fourteen of these individuals (20.9%) suffered fractured vertebrae, six (8.7%) during ejection and eight (12.2%) during landing.

"Minor" injuries were primarily superficial abrasions, contusions, and lacerations. The majority of these were caused by the harness system (ballistic inertia reel yoke and parachute saddle), followed by windblast pressure on the helmet and oxygen mask, and lastly, contact with cockpit surroundings during ejection.

Aircrew factors that contributed to injury were: improper position on ejection, loose restraint system and parachute harness, loose oxygen mask and helmet, and failure to release the seat pack prior to landing.

INTRODUCTION

During the period 1 January 1975 through 31 December 1987, one hundred and thirteen personnel were involved in "A" category mishaps [1] and one individual ejected from the rear seat of a CF116 when the cockpit filled with smoke. Of these 114 personnel, 78 attempted to eject from their aircraft, and 11 of these were killed representing a CF ejection success rate of (67/78) 85.9%.

Of the 67 successful ejections, nine individuals escaped without injury and 58 received various injuries at some point during the escape sequence. Nineteen of these individuals received "major" injuries, although none were considered life threatening. For the purposes of this report, a "major" injury was defined as any injury that:

a. required hospitalization for five or more days;

b. included the fracture of a bone (except nasal bones or phalanges);

c. resulted in the dislocation of a joint (except phalanges);

d. involved severe hemorrhage due to laceration, and/or nerve, muscle, or tendon damage;

f. resulted in third degree burns or secondary burns over 5% or more of the body surface; and/or

g. involved injury to internal organs.

This report will analyse ejection sequence injuries according to the phase in which they occur, determine the most probable mechanisms of injury, and make any pertinent recommendations for reduction in injury rate.

METHOD

All pertinent CF211 Board of Inquiry, "Separate Medical Officer's Reports", and "Reports of Emergency Escape from Aircraft" held on file at the Defence and Civil Institute of Environmental Medicine (DCIEM), Medical Life Support Division (MLSD) covering the period January 1975 through December 1987 were analysed for data. Included in the analysis were 80 flight operations "A" Category accidents and one non-"A" Category mishap where ejection was involved. Sixty-seven non-fatal ejection cases were identified for in-depth analysis.

The ejection escape sequence was divided into three phases for the purpose of this study.

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[1] An accident wherein the aircraft is damaged beyond economical repair.

Ejection Phase - This phase included all events from activation of the seat ejection handles or ejection "D" ring to rocket motor burn-out. Mechanical events include ejection system activation, ballistic inertia reel (BIR) retraction, canopy jettison, leg retraction (CF104 and CF188), ballistic impulse catapult firing, seat ejection, and rocket motor burn.

Descent Phase - Descent commences with rocket motor burn-out and terminates just prior to the landing phase. Mechanical events include separation from the ejection seat, freefall to parachute opening altitude (16000 ± 500 feet above sea level) if required, parachute deployment, release of the seat pack survival kit, and descent to ground or water.

Landing Phase - This phase comprises the time period from performing a ground or water landing to extrication from the parachute.

A detailed analysis of injury type, anatomical site, and the most probable cause mechanism was obtained primarily from the investigating Medical Officer's Report for each non-fatal ejection. In cases where the Medical Officer failed to comment on the cause of injury or was unable to determine a probable cause, use was made of the ejectee's "Report of Emergency Escape from Aircraft" and/or the Reviewing Officer's comments which often contained clues or rationale as to the cause of injury and in what phase the injury occurred. Failing this, the author subjectively assigned an injury cause factor based on the best available evidence. Each injury was, therefore, given a cause mechanism, classified as a "major" or "minor" injury, and listed as having occurred in one of the three escape sequences phases.

RESULTS AND DISCUSSION

One hundred fourteen personnel were involved in ejection seat related mishaps during this 13 year period: 36 made no apparent attempt to eject resulting in 28 fatalities; 78 attempted to eject - only 67 were successful.

Of the 36 individuals that did not attempt ejection, eight survived because they were on the ground at the time, performing either a landing or take-off roll.

Of the 78 that attempted to eject, 74 managed to egress the cockpit. One CT133 pilot was unable to initiate ejection due to a jammed seat firing handle, and another CT133 pilot completed the sequence milliseconds before aircraft impact. The ejection initiator cartridges had fired and the canopy jettisoned, however, aircraft impact severed the lines to the rocket catapult initiator and the seat did not eject. Two individuals flying in a CF104 may have been unable to eject as a result of the seat packs dislodging from the ejection seat pans under negative "G" and preventing the individuals from reaching the firing handle ("D" ring) located on the front of the seat pan. The aircraft was not equipped with negative "G" straps.

Sixty-seven of the 74 personnel who ejected survived. Of the seven fatal ejections, six were "out of the ejection envelope" [2] and one experienced parachute failure due to improper

[2] An out-of-envelope ejection situation is any adverse combination of aircraft flight parameters such as altitude, bank, pitch, airspeed, or sink rate that is outside the mechanical design parameters of the ejection system. Such condi-

strap-in and position on ejection. Interestingly, of the 67 surviving ejectees, one individual (a CF101 navigator) ejected "out of the envelope" while the aircraft was on the runway and landed in a snowbank receiving a compression fracture to the T3 vertebra.

Using a base figure of 78 attempted ejections, the CF ejection success rate for this 13 year period was (67/78) 85.9%. [3] This success rate is well below the ten year success rate (1972-1982) of 94% reported by Rowe and Brooks (2), but above the 35 year (1952-1987) average of 79.9% previously reported by this author (5).

Table 1 summarizes the CF ejection experience for this period by aircraft type. Although the number of ejections by type are insufficient to reveal statistically significant differences - especially between the CF116, CF188, and CT133, they do suggest a relatively poor success rate for the CT133. The author conducted an informal review of 157 aircrew involved in "A" category CT133 accidents since 1953 which tends to confirm this poor performance. Of these aircrew, perhaps 100 attempted ejection but only 88 completed the sequence and 72 survived. Of the 12 who were unable to complete ejection (due to system malfunction or other) six were killed. Thus the total number of CT133 fatalities arising out of 100 attempted ejections was 22, representing a 78% success rate over a 34 year period. It must be borne in mind, however, that the CT133 ejection system has undergone considerable change since it was brought on to the inventory, from a manual ballistic system to a semi-automatic system, and most recently to a rocket catapult (ROCAT) system. The first CT133 ROCAT ejection on 20 August 1980 was successful.

Table 2 presents the number of injured ejectees by aircraft type and the phase(s) of the ejection sequence in which injuries were incurred. Figure 1 illustrates the distribution of these 58 personnel by phase of occurrence. Twenty-one ejectees received their injuries only during the phase of ejection from the cockpit, three ejectees received injuries only during the descent phase, and four ejectees were injured only on landing. The remaining 30 ejectees received injuries during two or more of the escape sequence phases.

A detailed analysis of injury type was conducted on each of 58 surviving ejectees. One hundred and thirty-five injuries were identified for 54 ejectees during the ejection and descent phases (Table 3), and 40 injuries for 22 individuals were identified during the landing phase (Table 4).

Ejection and Descent Injuries - Superficial abrasions, lacerations, and contusions of a minor nature were the most frequently observed injuries, following in decreasing frequency by connective tissue (muscle/tendon/ligament) injury, fracture, flail, and burns.

Table 5 classifies these 135 injuries by cause factor. Injuries arising from the ballistic inertia reel (BIR) harness and the parachute harness predominate, followed by windblast

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tions vary between aircraft types due to different mechanical systems involved.

[3] It is quite possible that the CF104 exhibited a 100% ejection success record for this period. The death of two CF104 pilots attributed to an inability to eject because of seat pack dislodgement during a negative G jink-out manoeuvre is speculative though the primary cause factor of the mishap. If it is assumed that this is not the case, then the CF ejection success rate for this period would increase to 88.2%.

injuries, contact injuries, and ejection acceleration injuries. Of the 54 ejectees injured during these two phases, 11 received "major" injuries (fractured vertebrae, knee and shoulder flail, knee/seat contact and contact fracture).

Vertebral fracture could not be correlated with aircraft type and appeared to be dependent on individual circumstances at the moment of ejection (posture, aircraft dynamics). Figure 2 shows the site and distribution of vertebral fractures for ejection and landing.

Excluding fatal cases, six individuals (8.9%) fractured a total of 11 vertebrae on ejection and eight individuals (11.9%) fractured a total of 13 vertebrae on landing. Total vertebral fracture incidence was, therefore, (14/67) 20.8%. Smiley's data (3, 4) for 1952-1961 and 1962-1966 show fracture rates of 13.3% and 21.5% respectively. His early study did not include the CF101 and CF104 so the 13.3% fracture rate may be artificially low. The data for the 1962-1966 period is virtually identical to the fracture rate for this report period. It therefore appears that the RCAF/CF ejection and landing fracture rate has held constant near 21%.

The distribution pattern of ejection vertebral fracture and landing vertebral fracture show marked differences (Figure 2). Ejection vertebral fractures tend to be broadly distributed between T3 to L1 inclusive, while landing fractures are predominately "spiked" at L1. Six individuals (42.9%) exhibited multiple fractures of the spine. This figure agrees with the 40.8% multiple vertebral fracture rate reported for some NATO air forces (1).

Considering the advances in ejection system technology and training during the previous 25 years, it may appear surprising that the RCAF/CF vertebral fracture rate appears constant. Quite possibly the frequency of vertebral fracture mentioned in earlier reports may have been considerably underestimated as a result of a failure to detect or document spinal injuries. Auffret and Delahaye (1) note that 15 - 20% of vertebral fractures are asymptomatic and reveal no clinical manifestations. A decrease in the number of vertebral fractures coincident with improvements in ejection systems and training could have been masked by an increased detection rate concomitant with the employment of more sophisticated detection techniques in radiology and tomography.

All vertebrae damaged during the ejection phase, except possibly two from a CF188 ejection, were anterior compression fractures involving vertebral volume compression between 10 and 25%. There was no posterior wall involvement diagnosed nor neurological manifestations. One CF188 ejectee received four compression fractures on ejection including two (T12, L1) with possible anterior and left lateral compression (Figure 3). This may be the first instance of observed lateral compression fracture on ejection from CF aircraft. The front seat of the CF188 dual diverges to the right on ejection thereby imparting left lateral inertial forces to the ejectee. These forces may be aggravated if the aircraft is rolling right during ejection. It is distinctly possible that future CF188 ejectees may experience lateral vertebral compression fractures.

Windblast, or "Q" force, on ejection contributed to both "major" and "minor" injuries. Two individuals (3%) received injuries to joints as a result of flail. One, a navigator who ejected from a CF101 in excess of 350 knots at 5,000 feet, suffered severe right knee flail

injury. The other, a CF104 pilot, ejected at 90 feet and 500 knots, received a dislocated right shoulder. In general, "major" flail injuries during CF ejections are rare. Since 1972, over 80% of all CF ejections have been at or below 250 knots.

The effects of windblast were largely "minor" in nature. Injuries were primarily superficial facial abrasions and lacerations attributed to slippage and/or loss of the oxygen mask and helmet. Sites of injury frequently noted were the undersurface of the chin (helmet chinstrap), front of chin (mask exhalation valve or microphone), bridge of nose and forehead (mask edgeroll and supporting Pate Suspension), upper forehead (helmet edgeroll), lateral side of neck (communication cord, helmet nape strap), and back of head (helmed edgeroll, nape strap). Windblast contributed to the loss of seven helmets (10.5% loss rate). One individual who ejected at 430 knots at 1000 feet suffered a concussion with both retrograde and anterograde amnesia from head buffet following helmet loss.

Twenty-one ejectees (31.3% of non-fatal ejections) received injuries from body contact with cockpit structures or the ejection seat, resulting in a total of 31 injuries (23.0% of total injuries). The most common type of contact injury was left elbow abrasion or contusion. The left hand is normally operating the throttle, and is probably not in a good position during some ejections. As a result, left elbow contact with the armrest or canopy still occurs. Knee injury was also relatively common, and arose during the ejection phase when compression and "submarining" resulted in knee contact with the lower instrument panel or canopy bow. Lateral knee contusions were also observed in several cases, and probably arose when windblast forced the knees against the seat ejection handles.

Three individuals received non-spinal fractures. One received a comminuted fracture of the tip of the nasal bones and a fractured right clavicle thought to have resulted from seat contact during or following separation. One pilot ejected through the canopy of a CT114 Tutor aircraft incurring a fractured right ulnar styloid from collision with the canopy structure, and another pilot received a minor chip fracture of the right patella probably due to instrument panel or canopy bow contact.

The greatest number of injuries were caused by the BIR and parachute harness systems. Typical BIR harness injuries were abrasions to the lateral aspects of the neck during retraction, and contusions to the shoulder areas. BIR retraction forces may also have caused one case of shoulder "strain" (CF101) and one case of rib "strain" (CF104). The parachute harness and riser system contributed to approximately 30% of the total of ejection and descent injuries. Parachute opening resulted in some minor degree of groin abrasion or contusion. Shoulder abrasions were occasionally reported, and there were two cases of contusions to the axillae. Lateral and posterior thigh contusions were also noted. The majority of these harness injuries were probably due to the failure of the individual to adequately tighten the harnesses during seat strap-in.

Landing Injuries - Twenty-two individuals were injured on landing (Table 4), the majority of injuries being superficial abrasions, lacerations, and contusions due to landing in trees or on hard ground. One CF188 pilot received a "sprained" ankle, and one CT114 pilot a "contused" ankle, both attributed to improper landing.

Eight individuals received "major" injury in the form of vertebral fracture during landing, and five of these may have been compounded by failure in ability to release the seat pack. Figure 2 shows the distribution of 13 vertebrae fractured on landing. In contrast to the pattern of ejection vertebral fractures, landing fractures show a distinct "spike" at L1. The vertebral fracture-on-landing rate was 11.9%.

The most serious injury during this time period occurred to a CT133 pilot who ejected at low altitude and airspeed following engine flame-out on approach for landing. The individual did not release the seat pack due to a lack of time and landed improperly immediately feeling pain and parasthesiae in the legs. Subsequent radiography revealed a "burst" fracture of L1 with a 50% loss of vertebral volume, 0.25 inch protrusion into the spinal canal, and two fractured pedicles.

CT114 aircrew exhibited the highest rate of "major" injury (42.1%) with 75% of these personnel sustaining injuries on landing. Failure to release the seat pack prior to landing attributed to half of the injuries. One CT114 pilot suffered severe hyperflexion on landing with the seat pack on, so much so that the parachute quick-release box cut his chin and he received at 25% compression fracture of the anterior margins of four vertebrae (T12-L3), a contused lung, and possibly a contusion to the myocardium.

CONCLUSIONS

The CF ejection success rate over the 12 year period 1 January 1975 through 31 December 1987 was 85.9%. Eighty-six percent of the surviving ejectees received injuries during the escape sequence. Twenty-eight percent of the survivors received "major" injuries, with 16% of these occurring during ejection/descent and 12% on landing.

Vertebral fracture predominated in 14 of the 19 individuals with "major" injuries. Eight of these individuals received vertebral fracture on landing and six on ejection. Failure to release the seat pack may have predominated as the cause of vertebral fracture on landing. Vertebral fracture on ejection appeared to be dependent on circumstances such as seated posture and aircraft aerodynamics at the time of ejection. The distribution of vertebral fracture was different for ejection and landing. Landing fractures predominated at L1 while ejection fractures were more broadly distributed over T3 to L1. The incidence of vertebral fracture appears to have remained stable since 1962 at approximately 20%.

Flail injuries were exhibited by 3% of surviving ejectees, affecting knees and shoulders. There was one case of concussion amnesia from head buffet following helmet loss at 430 knots. All flail injuries occurred during ejections at airspeeds in excess of 350 knots.

"Minor" superficial injuries predominated throughout the ejection escape sequence. Fifty-eight of the 67 surviving ejectees received this type of injury. Injuries related to the harness predominated followed by windblast injuries, contact injuries, and ejection acceleration injuries.

The number of "minor" injuries could be reduced in the future if aircrew ensured their flight helmets and oxygen masks were snug on their faces at all times, helmets properly fitted, and visors down. They should also ensure parachute harnesses and lap belts are as tight as comfortably possible to reduce vertebral fracture on ejection due to dynamic overshoot from seat jolt or from submarining, and to reduce injury on parachute opening. Lastly, seat packs must be released before ground landing. This last action is especially important due to the apparent increased potential for serious back injury, loss of flying status, and permanent disability that may occur.

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Table 1. CF Ejection, Descent and Landing Injury Experience
January 1975 - December 1987

A/C Type	Attempted Ejections	Ejected From Cockpit	Successful Ejections	% Success *	Number With Injury			Major Injury Rate (%)
					Minor	Major	Fatal	
CF101 **	15	15	13	86.7	8	3	2	23.1
CF104 ***	19	17	17	89.5	13	3	-	17.6
CF116	8	8	8	100	6	1	-	12.5
CF188	5	5	5	100	3	2	-	40.0
CT133	8	6	5	62.5	3	2	2	40.0
CT114	23	23	19	82.6	8	8	4	42.1
Total	**78**	**74**	**67**	**85.9**	**50**	**19**	**8**	**28.4**

* % Success = Successful Ejections Compared to Attempted Ejections
** Removed from CF Inventory 1982

*** Removed from CF Inventory 1986

Table 2. Injured Ejectees by Aircraft Type and Phase of Escape

Aircraft Type	Number Crew Injured	Occurrence of Injury					
		Ejection		Descent		Landing	
		No.	(%)	No.	(%)	No.	(%)
CF101	11	9	(81.8)	6	(54.5)	4	(36.4)
CF104	15	12	(80.0)	5	(33.3)	5	(33.3)
CF116	7	6	(85.7)	1	(14.3)	1	(14.3)
CF188	4	4	(100)	2	(50.0)	1	(25.0)
CT133	5	5	(100)	1	(20.0)	3	(60.0)
CT114	16	10	(62.5)	9	(56.2)	8	(50.0)
Total *	**58**	**46**	**(79.3)**	**24**	**(41.4)**	**22**	**(37.9)**

* Percentages do not total 100% because some ejectees received injuries during more than one phase.

Table 3. Anatomical Site of 135 Injuries Sustained by 54 Ejectees Injured During Ejection and Descent

Injury Type and Number		No. Injuries and Site	Probable Cause
I	FRACTURES (15)	Vertebral - 11	Ejection Forces
		Clavicles - 1	Seat Contact
		Ulnar styloid - 1	Canopy contact
		Patella - 1	Instrument panel
		Nasal - 1	Seat Contact
II	CONNECTIVE TISSUE (19)	Vertebral - 15	Ejection Forces
		Shoulder - 1	BIR Retraction
		Knee - 2	Seat Contact
		Ribs - 1	BIR Retraction
III	FLAIL (5)	Shoulder Dislocation - 1	Windblast
		Shoulder Sprain - 2	Windblast
		Concussion - 1	Windblast Buffet
		Knee Ligaments - 1	Windblast
IV	SUPERFICIAL ABRASIONS, LACERATIONS, CONTUSIONS (93)	Head/Face - 28	Windblast - 27
			Canopy Contact - 1
		Groin - 16	Parachute Opening - 16
		Thigh - 11	Parachute Opening - 8
			Seat Contact - 3
		Shoulder - 9	Parachute Opening - 4
			BIR - 5
		Cervical - 7	BIR - 4
			Parachute Opening - 2
			Windblast - 1
		Elbows - 7	Sill Contact - 10
			Strobe Light - 1
		Knees - 6	Seat - 3
			Canopy - 2
			Instrument Panel - 1
		Feet - 3	Pedals/Inst. Panel (?) - 3
		Shin - 3	Canopy - 2
			Instrument Panel - 1
		Arms - 1	Seat
		Tongue - 1	Acceleration
		Chest - 1	Canopy
V	BURNS (3)	Elbow - 1	*ROCAT
		Leg - 2	

* ROCAT = (Roc)ket (cat)apult

Table 4. Anatomical Site of 40 Injuries Sustained by 22 Ejectees Injured During Landing

Injury Type and Number		Injury Site and Number	Contributing Factors
I	FRACTURES (13)	Vertebral - 13	Seat Pack - 6 Hard Landing - 7
II	CONNECTIVE TISSUE * (3)	Vertebral - 2 Ankle - 1	Hard Landing - (?)
III	ORGANS (2)	Contused Myocardium - 1 and lungs - 1	Improper landing Severe Flexion
IV	SUPERFICIAL ABRASIONS, LACERATIONS, CONTUSIONS (22)	Thigh - 5	Miscellaneous landing
		Shin - 3	
		Elbow - 3	
		Face - 2	
		Ankle - 1	
		Feet - 3	
		Shoulder - 1	Tree
		Wrist - 1	
		Knee - 1	
		Eye - 1	Tree
		Sternum - 1	QRB

* Injury to Muscular, tendinous, or ligamentous tissues.

Table 5. Mechanism of 135 Ejection and Descent Injuries for 54 Ejectees

Mechanism No. Injuries and (%)	Injury Type	Number of Injuries Minor	Major
ROCKET CATAPULT 3 (2.2)	Burns	3	-
* EJECTION ACCELERATION 27 (20.0)	Vertebral Fracture	-	11
	Vertebral Strain	15	-
	Tongue Lacerations	1	-
WINDBLAST 33 (24.4)	Superficial	28	-
	Flail Injury	3	2
CONTACT 31 (23.0)	Fracture	1	3
	Connective Tissue **	1	1
	Superficial	25	-
PARACHUTE HARNESS / BIR 41 (30.4)	Superficial	39	-
	Connective Tissue	2	-

* In addition there were nine cases of possible transient loss of consciousness, amnesia, or confusion due to ejection "G" forces.

** Injury to muscular, tendinous, or ligamentous tissues.

Figure 1. Distribution of 58 Injury Cases (and Percentage) According to Phase of Occurrence

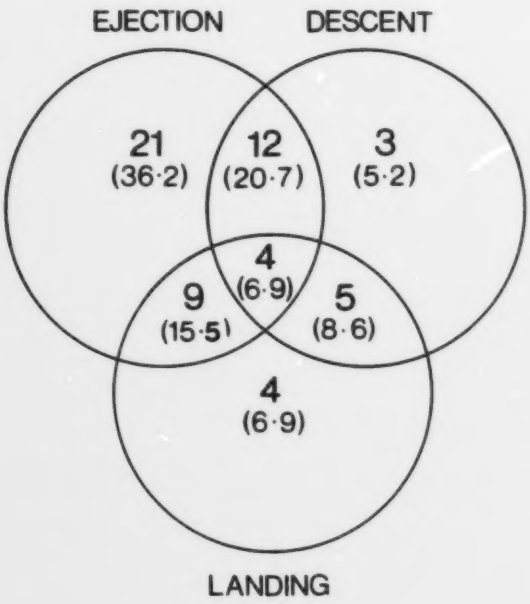


Figure 2. Site of Vertebral Fracture

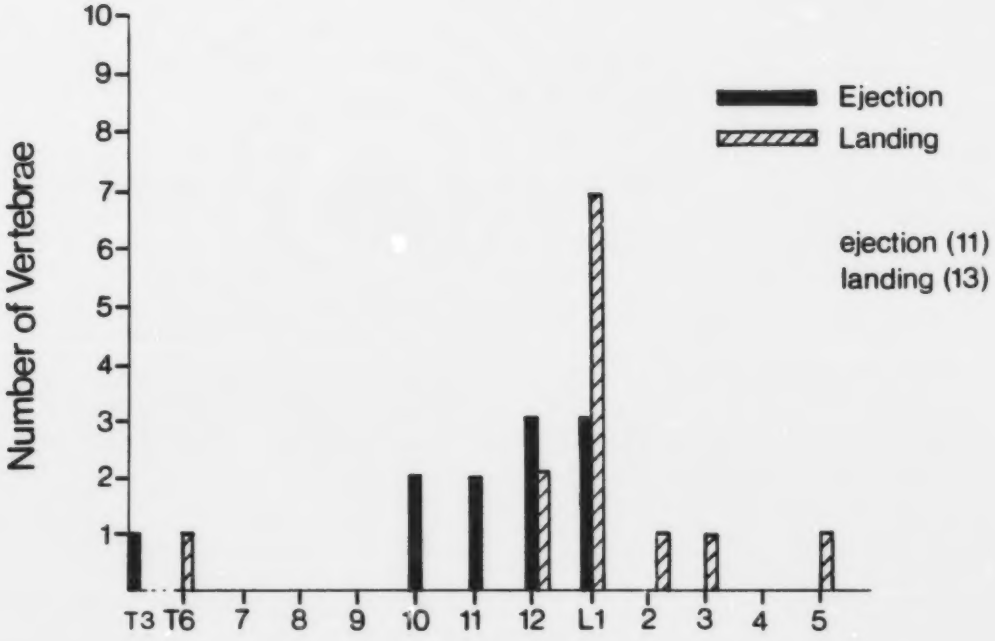
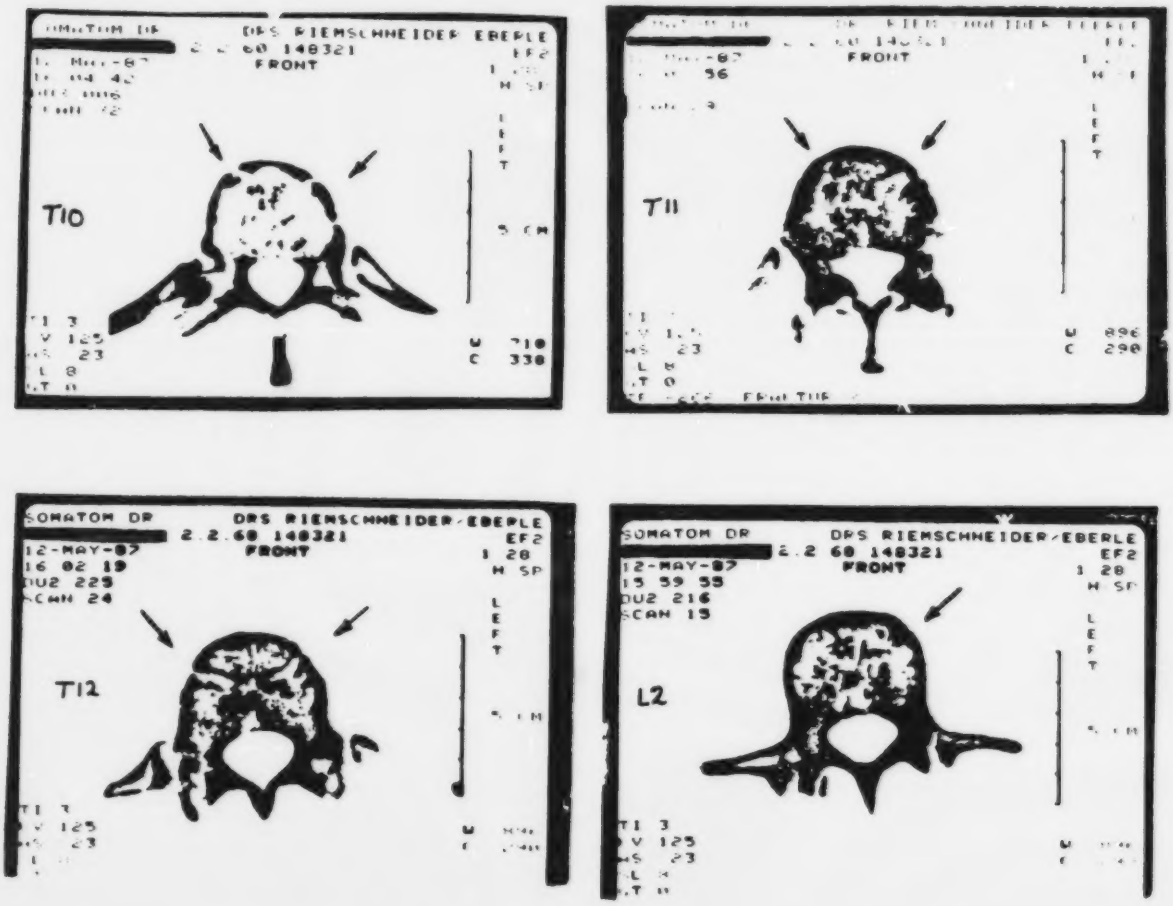


Figure 3. Anterior and Left Lateral Ejection Fracture
From Ejection from a CF188 Aircraft



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This report documents both major and minor non-fatal injuries and their causative mechanisms related to ejection from Canadian Forces aircraft.

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Parachutes

Windblast

Vertebral fracture

Acceleration

flail